Science and the Human Exploration of Mars: Risks to the Crew on the Surface

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Primary Factors of Effective Human Performance

- Low fatigue
- Alertness

[Sleep/circadian assessment]

- **Healthy brain and mood**
- **Focused concentration**

[Behavioral medicine]

To Think + To Act = **To Perform**

- Adapted to workplace
- Motivated

[Operational psychology]

- Physical interface to workplace
- Sensible workload

[Human-to-system interface]

Crew Autonomy

Crew health care

- Radiation Protection
- Medical Surgical care
- Nutrition - Food Supply
- Psychological support
  - meaningful work
    - surface science
      - **planetary**
      - **biomedical**
    - simulations of Mars launch, trans-Earth injection, and contingencies
    - progressive debriefs, sample processing, etc.
    - housekeeping
  - communications capability

Habitat

- Maintenance/housekeeping
  - workshop with HRET capabilities
- Exercise supplemental to Mars surface activities
- Recreation
- Privacy

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Bioastronautics Critical Path Roadmap (CPR)

CPR: blueprint for focused evolving research and technology for “risk reduction” to prevent or reduce the risks to humans in space environment

- Mars Design Reference Mission (1997) - “most challenging” scenario
- Identified: 55 risks, 343 critical questions in 12 risk areas

- Habitation systems
  - Advanced life support
  - Environmental health monitoring
  - Food and nutrition
- Medical care systems
  - Clinical capabilities
  - Multi-system (cross-risk) alterations

- Adaptation and countermeasure systems
  - Bone loss
  - Cardiovascular alterations
  - Human behavior and performance
  - Immunology, infection and hematology
  - Muscle alterations
  - Neurovestibular adaptation
  - Radiation effects

- Subset specific to surface ops: **35 risks, 233 critical questions**

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CPR Issues: Radiation

CPR: Radiation effects (possible synergy with hypogravity, other environmental factors)

- Early or Acute Effects from Radiation Exposure (esp. damage to Central Nervous System)
- Carcinogenesis Caused by Radiation

Issue: Surface Radiation Environment

- Large uncertainties about biological effects of GCR, SPE now prevent meaningful risk assessment (-)
- Possible risk from neutron backscatter from surface (-)
- EMU now not effective shielding (mobility $\propto$ protection^{-1}) (-)
- Attenuation of GCR & SPE by atmosphere, bulk of planet (+)
- Habitat, rovers assumed to provide storm shelters (+)
- Countermeasures (+)
  - Shielding: HDPE, H_2O
  - Chemopreventative/chemoprotective pharmaceuticals: possible cocktail of antioxidants, free-radical scavengers, toxic clearance agents

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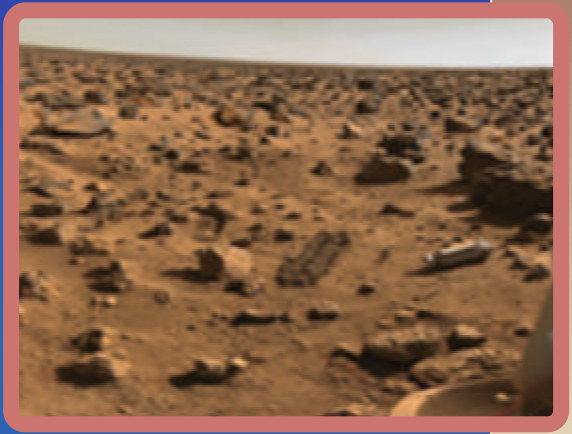
CPR Issues: Environmental

- **Issue: Dust**
  - Operational: fouling of habitat or pressure garment fittings and mechanisms could pose risk to health and safety
  - Medical: possible risk if inhaled
    - Physical irritant
    - Reactive and oxidizing
    - Pulmonary inflammation

      effects likely additive
- **Issue: Biohazards**
  - Dependent on extant biological activity
    - Possible health threat to crew (maybe not)
    - Planetary protection issues (Mars as well as Earth)



- **CPR: Immune/Infection/Hematology**
  - Allergies and Hypersensitivity Reactions
  - Immunodeficiency and susceptibility to infections
  - Altered Wound Healing

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CPR Issues: Hypogravity

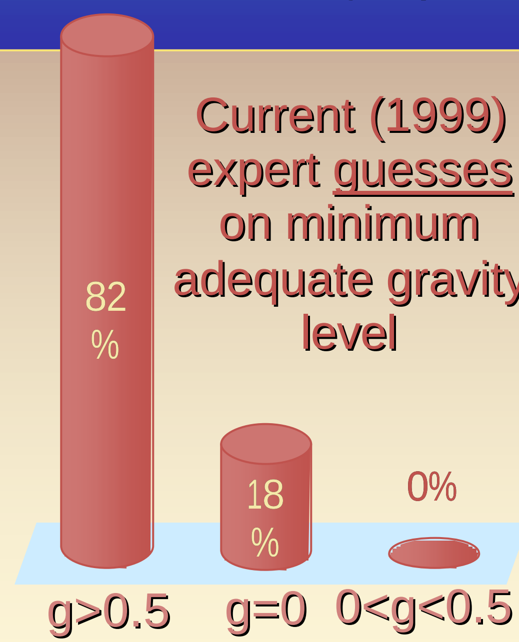
Issue: Efficacy of 0.38 g in countering deconditioning = ???
Therefore, Mars surface gravity <u>assumed</u> to be:

- Too ***LOW*** to be beneficial (for preserving bone integrity, etc.)
- Too ***HIGH*** to be ignored (for avoiding g-transition & vestibular symptoms)

Periodic health monitoring will also serve as applied research:

- probably longest period away from Earth to date
- probably longest exposure to hypogravity (0<g<1) to date

Current (1999) expert <u>guesses</u> on minimum adequate gravity level



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CPR Issues: Hypogravity (continued)

Physical tolerance of stresses during aerobraking, landing, and launch phases, and strenuous surface activities

- **CPR: Musculo-skeletal atrophy**
  - Inability to perform tasks due to loss of skeletal muscle mass, strength, and/or endurance
  - Injury of muscle, bone, and connective tissue
  - Fracture and impaired fracture healing
  - Renal stone formation
- **CPR: Cardiovascular alterations**
  - Manifestation of serious cardiac dysrhythmias and latent disease
  - Impaired cardiovascular response to orthostatic stress and to exercise stress
- **CPR: Neurovestibular alterations (possible synergy with radiation)**
  - Disorientation
  - Impaired coordination
  - Impaired cognition

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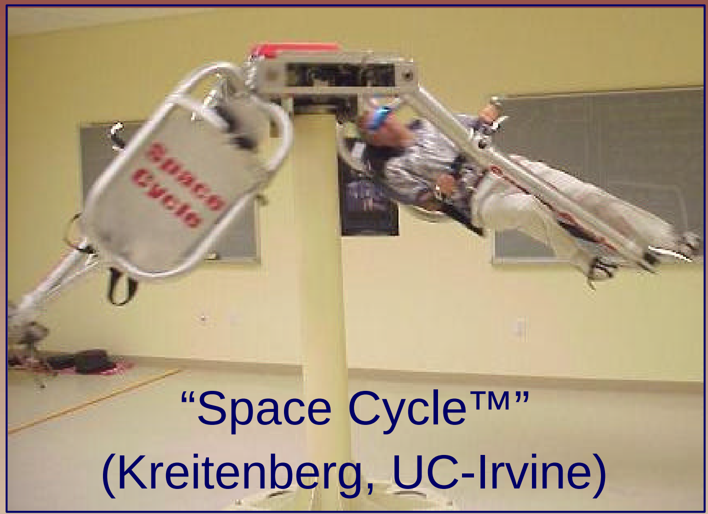
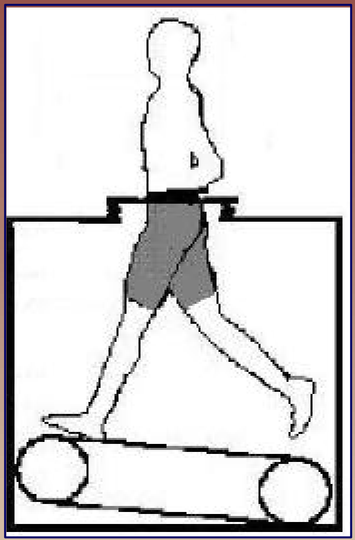
“Gravity Augmentation” During Exercise On Mars Surface

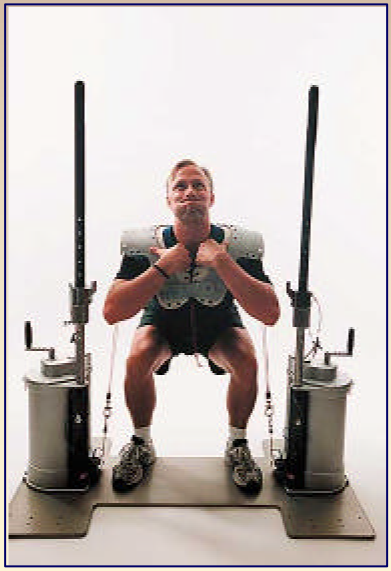
Concepts



“Space Cycle™”
(Kreitenberg, UC-Irvine)



Exercise in LBNP
(Hargens, NASA ARC)



ISS Interim Resistive Exercise Device
(Schneider, NASA JSC)

Self-Generated LBNP
(Hargens, NASA ARC)

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CPR Issues:
Human Behavior and Performance

Issues:

- Small group size
- Multi-cultural composition
- Extended duration
- Remote location
- High autonomy
- High risk (both expensive & life-threatening)
- High visibility (e.g., high pressure to succeed)

CPR: Behavior and Performance

- Sleep and circadian rhythm problems
- Poor psychosocial adaptation
- Neurobehavioral dysfunction
- Human-robotic interface

CPR Issues:
Human Behavior and Performance

Issue: Circadian Rhythm

- Sol = 24.62 hr
  - Human intrinsic rhythm = 24.1 ± 0.15 hr
    - synchronization not assured – may require (chronic) intervention?
- Synchronization successful (best case): Unknown efficacy in maintaining circadian health
  - Daylight EVA ops: safety, efficiency
  - Shorten perceived stay (by 2.5% !)
  - Complicate Earth-based support (ref. Viking, Pathfinder/Sojourner; MER 2003 plng)
- Failure to synchronize (worst case):
  - Crew awake during Mars night every 41 days (40 sols)
    - Well-rested “night-time” ops vs. fatigued daylight ops
    - -200 deg F temperature
      - EMU issues
    - Limited visibility (no IR capability): increased risk of accident, trauma
  - Radiation minimized: reduced SPE influence at night (?)

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Clinical Problems

Require appropriate medical capability

CPR: Medical care systems for prevention, diagnosis or treatment

- Difficulty of rehabilitation following landing
- Trauma and acute medical problems
- Illness and ambulatory health problems
- Altered pharmacodynamics and adverse drug reaction

- **Expected illnesses and problems**
  - **Orthopedic and musculoskeletal problems (esp. in hypogravity)**
  - **Infectious, hematological, and immune-related diseases**
  - **Dermatological, ophthalmologic, and ENT problems**
- **Acute medical emergencies**
  - **Wounds, lacerations, and burns**
  - **Toxic exposure and acute anaphylaxis**
  - **Acute radiation illness**
  - **Development and treatment of decompression sickness**
  - **Dental, ophthalmologic, and psychiatric**
- **Chronic diseases**
  - **Radiation-induced problems**
  - **Responses to dust exposure**
  - **Presentation or acute manifestation of nascent illness**

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Projected Rates of Illness or Injury

Past Experience

0.06 person/year

Based on U.S. and Russian space flight data, U.S. astronaut longitudinal data, and submarine, Antarctic winter-over, and military aviation experience:

- Incidence of *significant* illness or injury is **0.06 persons per year**
  - as defined by U.S. standards
  - requiring emergency room (ER) visit or hospital admission
- Subset requiring intensive care (ICU) support is **0.02 person per year**

Mars DRM

0.90 person/mission

For DRM of 6 crewmembers on a 2½ year mission, expect:

- **0.9 persons per mission,** or ~one person per mission, to require ER capability
- **0.3 persons per mission,** or ~once per three missions, to require ICU capability
  - ~80% require intensive care only 4-5 days
  - ~20% do not.

Note: Decreased productivity, increased risk while crew reduced by 1-2 (including care-giver)

Data from R. Billica, January 1998, and D. Hamilton, June 1998

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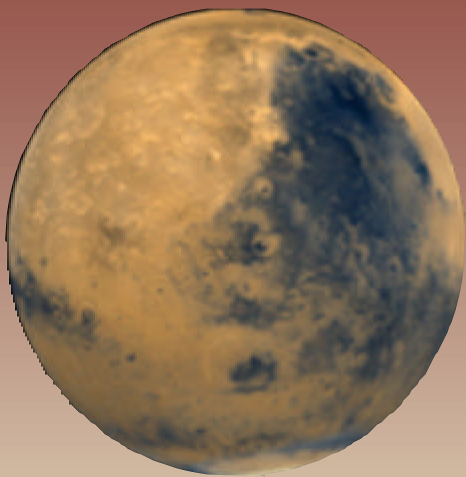
Conclusions



- The human element is the most complex element of the mission design
- Planetary missions will pose significant physiological and psychological challenges to crew members
- Human engineering, human robotic/machine interface, and life support issues are critical
- The Critical Path Roadmap Project has identified issues that may be show-stoppers (bone, radiation)
- The ISS platform must be used to address exploration issues before any “Go/No Go” decision
- A significant amount of ground-based and specialized flight research will be required to support Crewed Planetary Expeditions

Backup charts

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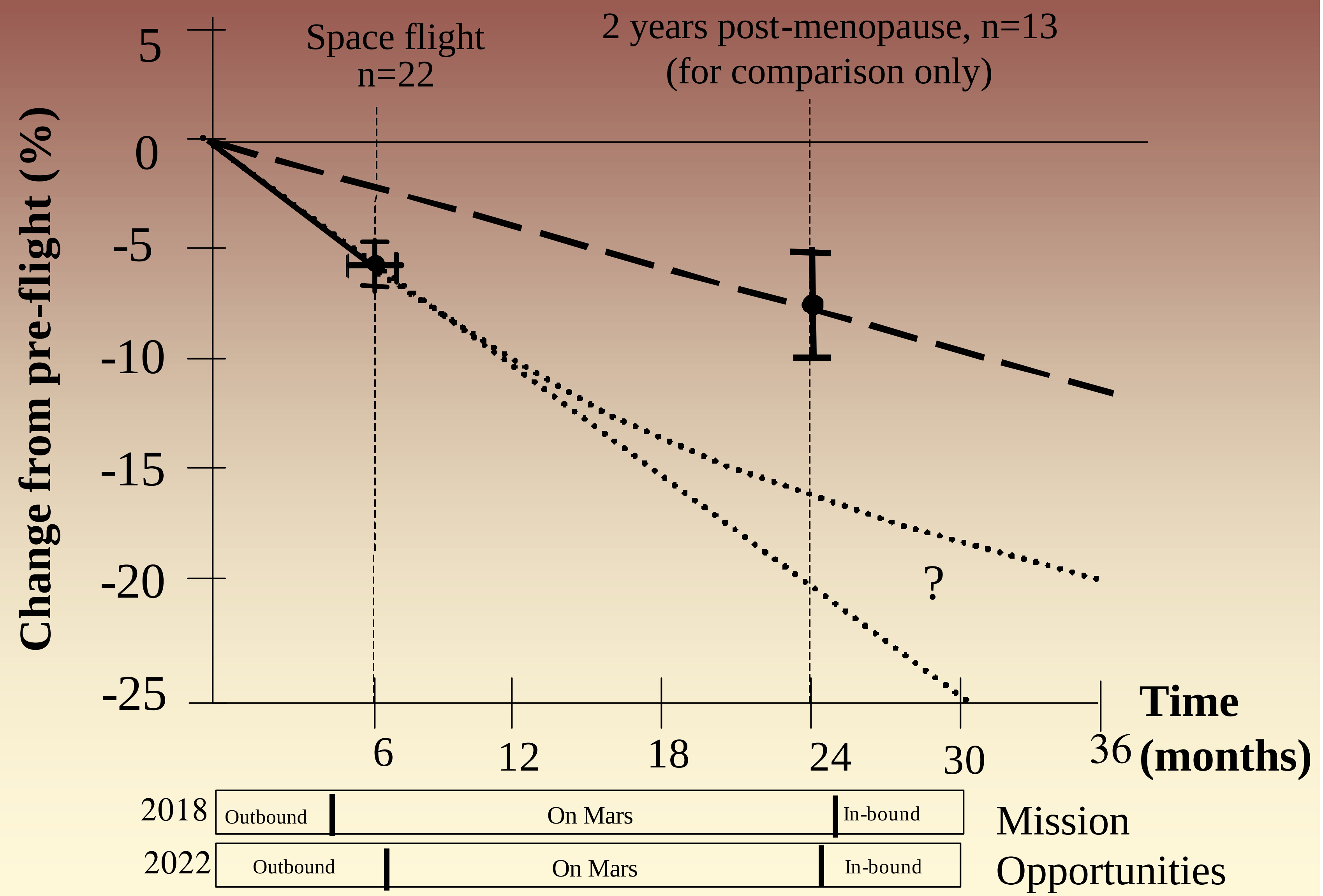
Bone Integrity in Weightlessness



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Strategy for Transition from Flight to Mars Surface Operations

Background

Anecdotal evidence suggests ~50% of Russian *Mir* crewmembers were ambulatory *with assistance* immediately after landing, increasing to nearly 100% within hours (with effort), then decreasing for days thereafter, before gradual recovery

Assume

Only 3 out of 6 Mars crewmembers are ambulatory immediately after landing

Strategy

Start with passive tasks, progress to strenuous tasks

- **First 1-3 days** activities limited to reconfiguration of lander/habitat and surface reconnaissance
- **Then**, conduct first Mars walk(s) in vicinity of lander (umbilical instead of backpack?)
- **Next,** use unpressurized rover for early, shorter excursions
- **After a week or more**, extended excursions are possible